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Migration and diving behavior of Kemp's ridley (Garman) sea turtles along the U.S. southeastern Atlantic coast

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Abstract

Three Kemp's ridley (*Lepidochelys kempii*, Garman) sea turtles were tracked with satellite and radio/sonic telemetry from release points along the Georgia coast beginning in October 1991. The movement demonstrated by these turtles was consistent with seasonal, coastal migration. Radio-tagged juveniles travelled south from Georgia to Florida a distance of 120 and 202 km during 41 and 29 days of monitoring, respectively. Submergence duration was significantly longer at night than during the day for one of two juvenile turtles. A nesting-sized Kemp's ridley tracked via satellite telemetry from October 1991 to July 1992 made longer dives than the radio tagged juveniles, but the percent submergence time was very similar, 94% and 95%, respectively. Seasonal and day–night differences in average submergence duration were significant for the satellite tracked turtle, and longer dives occurred at night throughout all seasons. In spring, average submergence duration was shorter. From mid-November to mid-March the primary overwintering grounds of the nesting-sized ridley sea turtle were within approximately 40 km of the Atlantic coast between Cape Canaveral and Stuart, Florida. During late spring and early summer, coastal South Carolina was the preferred habitat of this individual.

Keywords: Diving behavior; Kemp's ridley; Migration; Sea turtle

1. Introduction

The Kemp's ridley sea turtle (*Lepidochelys kempii*, Garman) is the smallest and most endangered of the five species of sea turtles indigenous to U.S. waters. Breeding occurs in spring and summer on a single nesting beach in Rancho Nuevo, Mexico, although a few sporadic nestings have been reported elsewhere (Pritchard, 1989; Marquez, 1990). The species is found in the Gulf of Mexico and along the western coast of the Atlantic Ocean (Bleakney, 1955; Henwood and Ogren, 1987; Marquez, 1990). The northern part

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of its range is occupied by juveniles and subadults (Ogren, 1989). Recoveries of tagged, headstarted Kemp's ridleys released in the Gulf of Mexico were reported from the U.S. Atlantic seaboard as well as from France and Morocco (Fontaine et al., 1989). This suggests travel along the east coast of North America and occasional transport of waifs across the Atlantic via the Gulf Stream (Carr, 1980). Whether ridleys occurring in the Atlantic are lost to the reproductive population has long been a subject of debate (Pritchard, 1989).

Information on seasonal distribution, movement, and behavior of Kemp's ridley sea turtles along the U.S. Atlantic coast is limited (Henwood and Ogren, 1987; Danton and Prescott, 1988; Standora et al., 1989; Renaud, 1990; Standora et al., 1990). The U.S. Army Corps of Engineers (COE) South Atlantic District conducted periodic trawling surveys in selected east coast channels in recent years to provide data needed to protect sea turtles from incidental mortality in hopper dredges maintaining navigable channels (Slay and Richardson, 1988; Dickerson et al., 1993). While loggerhead sea turtles were frequently captured during trawling activities conducted by the COE in October 1991, the capture of three Kemp's ridleys provided a unique opportunity to study the movements and diving behavior of Kemp's ridley sea turtles on the Atlantic Coast. This information is essential to proper management of this natural resource and to protection of this highly endangered species from impacts of human activity.

2. Materials and methods

2.1. Sea turtle capture

The University of Georgia's R/V Bulldog, dragging two shrimp trawls each with an 18.3 m headrope and 20.3 cm stretch mesh, collected two juvenile Kemp's ridley sea turtles during repetitive 30 min tows near the mouth of Brunswick Channel, Georgia and one adult or subadult female Kemp's ridley in St. Mary's Channel approximately 11 km offshore. Maturity was determined by size. Carapace length greater than 59.5 cm was the minimum size of mature nesters (Chavez et al., 1967). Sex determination of the largest turtle was based on tail length; the tail of females barely extends beyond the carapace whereas that of males is markedly longer in mature individuals. All sea turtles were held separately in outdoor tanks for 4–5 days while awaiting tag attachment and subsequent release at capture locations (Table 1).

Table 1
Size, sex, capture and tracking dates of three Kemp's ridley sea turtles monitored off the U.S. Atlantic coast during 1991–1992.

Individual	SCL[a](cm)	SCW[b](cm)	Sex	Capture date	Tracking dates	Tag
Ridley No. 1	37.5	37.5	–	10/01/91	10/05/91–11/14/91	Radio/Sonic
Ridley No. 2	41.9	37.5	–	10/02/91	10/06/91–11/03/91	Radio/Sonic
Ridley No. 3	60.7	60.6	F	10/08/91	10/13/91–07/01/92	Satellite

[a] Straight carapace length.
[b] Straight carapace width.

2.2. Transmitter attachment

Radio, sonic, and depth-sensitive sonic transmitters were attached to the two juvenile Kemp's ridleys (Table 1). Sea turtles were removed from water and the carapace dried prior to attaching radio transmitters (Telonics (Telonics, Mesa, AZ, USA) Model 400, dimensions $3.8 \times 3.3 \times 6.1$ cm, 180 g). A two-part epoxy mix was used to build a flat platform on top of the anterior portion of the dorsal ridge. Additional epoxy was used to secure the base of the radio transmitter to the platform. Two layers of epoxy resin and fiberglass cloth were then applied across the longitudinal and cross-sectional axes of the transmitter to secure the unit to the carapace.

A cylindrical, depth-sensitive sonic transmitter measuring 1.9 cm diameter $\times$ 8.1 cm and weighing 34 g was attached to each sea turtle with wire inserted through a hole drilled in the most posterior marginal scute. A second sonic transmitter (not depth-sensitive) was attached to lateral, marginal scutes using nuts and bolts that would eventually corrode and detach from the animals.

The Kemp's ridley (33.6 kg) captured in St. Mary's Channel was fitted with a Telonics ST-3 satellite transmitter ($3.8 \times 10.8 \times 14.0$ cm, 817 g). Attachment procedures were identical to those used for the radio transmitters.

2.3. Radio and sonic tracking

The radio tracking system was comprised of a directional, five element Yagi antenna and an omnidirectional antenna wired to a Telonics TR2/TS1 receiver/scanner. A directional H-antenna was occasionally substituted for the Yagi antenna. Radio tags transmitted on separate frequencies in the 165 MHz band. Radio tags were tested prior to attachment to experimental animals to verify transmittance frequencies.

Directional hydrophones and receivers with adjustable frequency modulation were used to monitor sonic signals at distances up to 1 km. Depth-sensitive and standard sonic transmitters were tested to verify the transmittance frequency prior to attachment to experimental animals. A Sonotronics (Sonotronics, Tucson, AZ, USA) digital receiver (USR-SB) with directional hydrophone was used to monitor signals from depth-sensitive tags in the 68–80 kHz range, and a Dukane (Dukane, St. Charles, IL, USA) receiver (N3OA5B) with directional hydrophone was used for standard sonic tags transmitting at a frequency of 32.7 kHz. Each tag had a unique pulse interval for identification.

Tracking was initially conducted from vessels which enabled personnel to record visual sightings of experimental animals when they surfaced. Nearly all shipboard tracking occurred during the day. When sea turtles became separated by large distances or when high seas prevented offshore tracking by vessel, monitoring was conducted from land using radio telemetry at a variety of locations including piers, beaches, lighthouses, and condominiums. Although most land-based tracking occurred during the day, some nighttime monitoring and continuous 24 h monitoring sessions were conducted. When no signals were received, aerial surveys were conducted to relocate sea turtles using directional radio antennas secured to the wing struts of planes.

Data collection included time of surfacing and submergence events, latitude, longitude, and compass bearing to the signal. Locations were determined with a Global

Positioning System that utilized satellites to compute latitude and longitude. LORAN C provided a backup. Surface and bottom water temperature and salinity were collected opportunistically.

2.4. Satellite tracking

Data from the satellite tag were processed through the ARGOS (Service ARGOS, Landover, MD, USA) satellite telemetry system and downloaded in the laboratory to personal computers (Priede and French, 1981; Fancy et al., 1988; Hays et al., 1991). The satellite tag stored data in two 12 h buffers (0700–1900 and 1900–0700 EST). New data were continuously recorded by overwriting one buffer and then the other regardless of whether previously stored data had been transmitted. Data from a continuous 12 h period were transmitted from the tag during 10 of every 60 h. Data were only received when orbiting satellites were overhead. Maximum time between successive data retrievals was 12 days. Data retrieved from each 12 h buffer included average submergence duration, duration of last submergence before a transmission, number of dives, tag temperature (approximately ± 2 °C (Bill Burger, Telonics)), and latitude and longitude. Codes associated with each position described accuracy as ± 150 m, ± 350 m, ± 1 km, or unknown. Satellite imagery collected by an AVHRR (advanced very high resolution radiometer) sensor aboard the NOAA 11 polar orbiting satellite provided data on sea surface temperature accurate to < 1 °C in cloud free images (McClain et al., 1985).

2.5. Analysis

Behavioral data collected during a 2-day acclimation period after release were not included in the analysis. Surfacing and diving behavior of radio tagged sea turtles were analyzed using t-tests. Day and night periods were defined somewhat differently for radio (0630–1800 and 1800–0630 EST) and satellite (0700–1900 and 1900–0700 EST) telemetry analysis due to the relative duration of the studies. The periods used for radio tracking data were appropriate for fall, while those for satellite data represented an approximation suitable for fall, winter and spring.

Positions of sea turtles were plotted on charts to determine movements. When visual or sonic contact was made with a tagged sea turtle, the location was plotted at the latitude and longitude of the tracking vessel because of the proximity between sea turtle and tracker. During radio monitoring from positions on land, bearings taken with a handheld compass from a directional radio antenna to the sea turtle were plotted and positions determined using the Locate II computer program (Pacer, Nova Scotia, Canada).

For data retrieved via satellite, seasonal and day/night differences in percentage of submergence time (number of dives × average dive duration/12 h period), mean dive duration, number of dives, duration of last dive prior to each data transmission, and tag temperature were determined using ANOVAs. The multiple comparisons procedure (Conover, 1980) was used in conjunction with the Kruskal-Wallis test to identify seasonal differences in percentage of submergence time. Seasons were defined as winter (January to March), spring (April to June), summer (July to September), and fall (October to December). Means reported in the results, are shown with plus or minus one standard error. Rate of net movement was calculated by dividing the distance travelled by the time interval between successive satellite transmissions.

The relationship between sea turtle movement and water temperature was investigated in two ways. Turtle locations were plotted on charts of AVHRR sea surface temperature data for days on which both a clear image and turtle positions were available. Unfortunately, these positions were coded for unknown accuracy, a common occurrence with satellite data, which restricted interpretation of the temperature data to broad areas (groundtruthing of unknowns in a different study yielded a mean error of 14.7 km; Standora et al., 1991) around the plotted positions. Tag temperature was also used as an indication of water temperature.

3. Results

3.1. Movement and migration

3.1.1. Kemp's ridley No. 1

Kemp's ridley No. 1 (R1), a juvenile measuring 38 cm straight carapace length (SCL), was released near its capture location in the Brunswick Channel between Jekyll and St. Simon's Islands (Fig. 1). During the first 2 days after release, the sea turtle moved into the Atlantic Ocean and was found either in the Brunswick Channel or within approximately 2 km of the channel and not more than 5 km offshore. High seas and a malfunctioning radio receiver hindered data collection during the first 10 days. From 11–20 days after release, R1 was located approximately 37–46 km south of the release site always within a few km either north or south of St. Mary's Channel. During the next 10 days the sea turtle was found in an area extending from St. Mary's Channel to about 11 km south, despite the passage of an offshore hurricane which resulted in very strong southerly currents. During the final 10 days of monitoring, R1 moved further south to a location approximately half the distance between Jacksonville and St. Augustine, Florida. This sea turtle travelled 120 km south during 41 days at large. Visual sightings and sonic telemetry always placed R1 within 16 km of shore in depths less than 20 m while triangulation located the sea turtle as far as 27 km offshore where maximum water depths were 18–21 m.

3.1.2. Kemp's ridley No. 2

This juvenile (R2) measuring 42 cm SCL was captured and released near the same location in the Brunswick Channel as R1 (Fig. 2). During the first day after release, the sea turtle was observed in the channel moving west into the sound. However, R2 reversed its course and moved into the Atlantic Ocean where triangulation of radio bearings plotted it off Cumberland Island 2 days later. During 11–20 days at large, the sea turtle was found from the southern end of Cumberland Island to a few km south of St. Mary's Channel. During the next 10 days R2 moved south much more rapidly than R1. This movement began before an offshore hurricane brought high seas and a strong, southerly current, and continued until after the high winds of 29 October subsided. R2

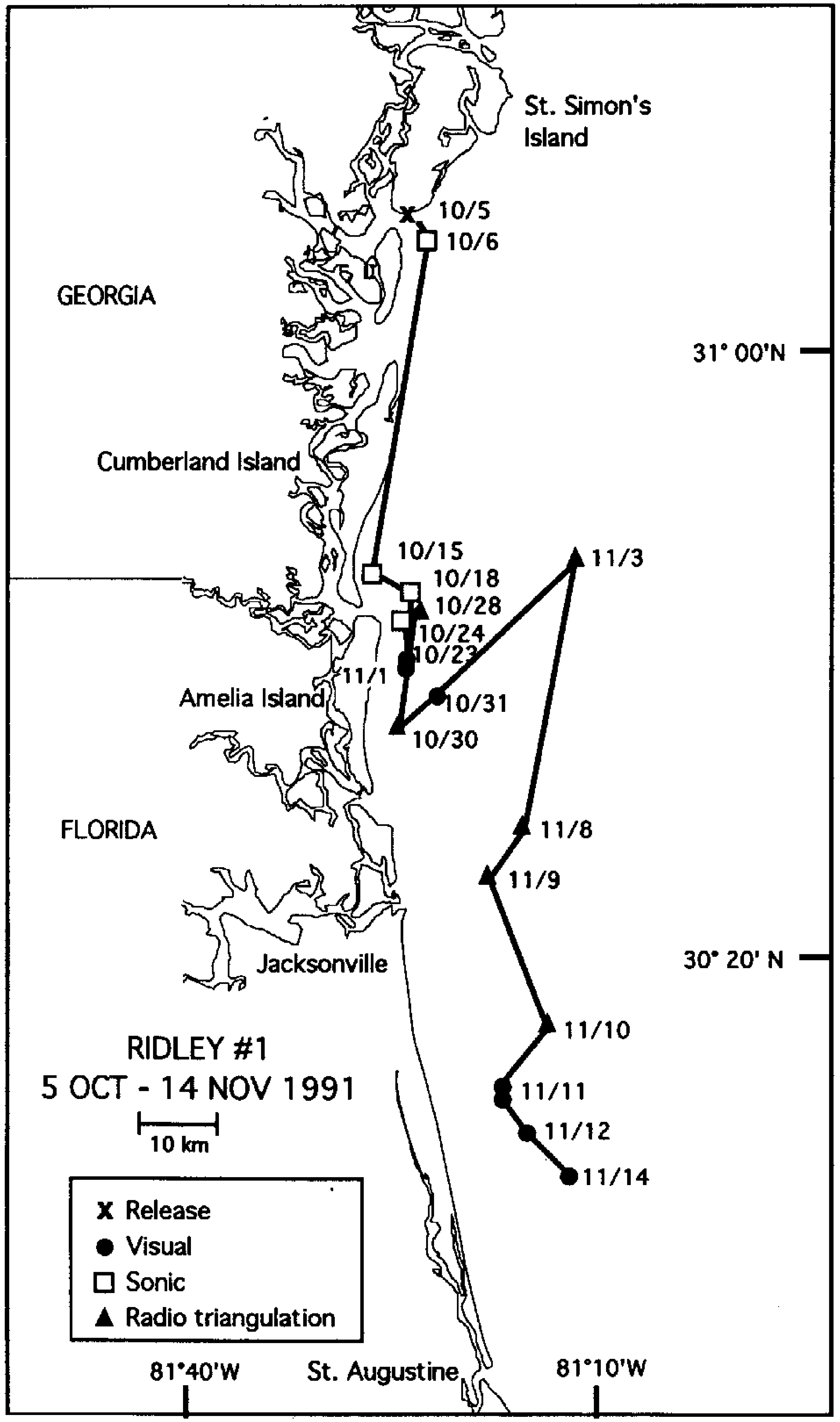

Fig. 1. Locations of Kemp's Ridley No. 1 from 5 October–14 November 1991.

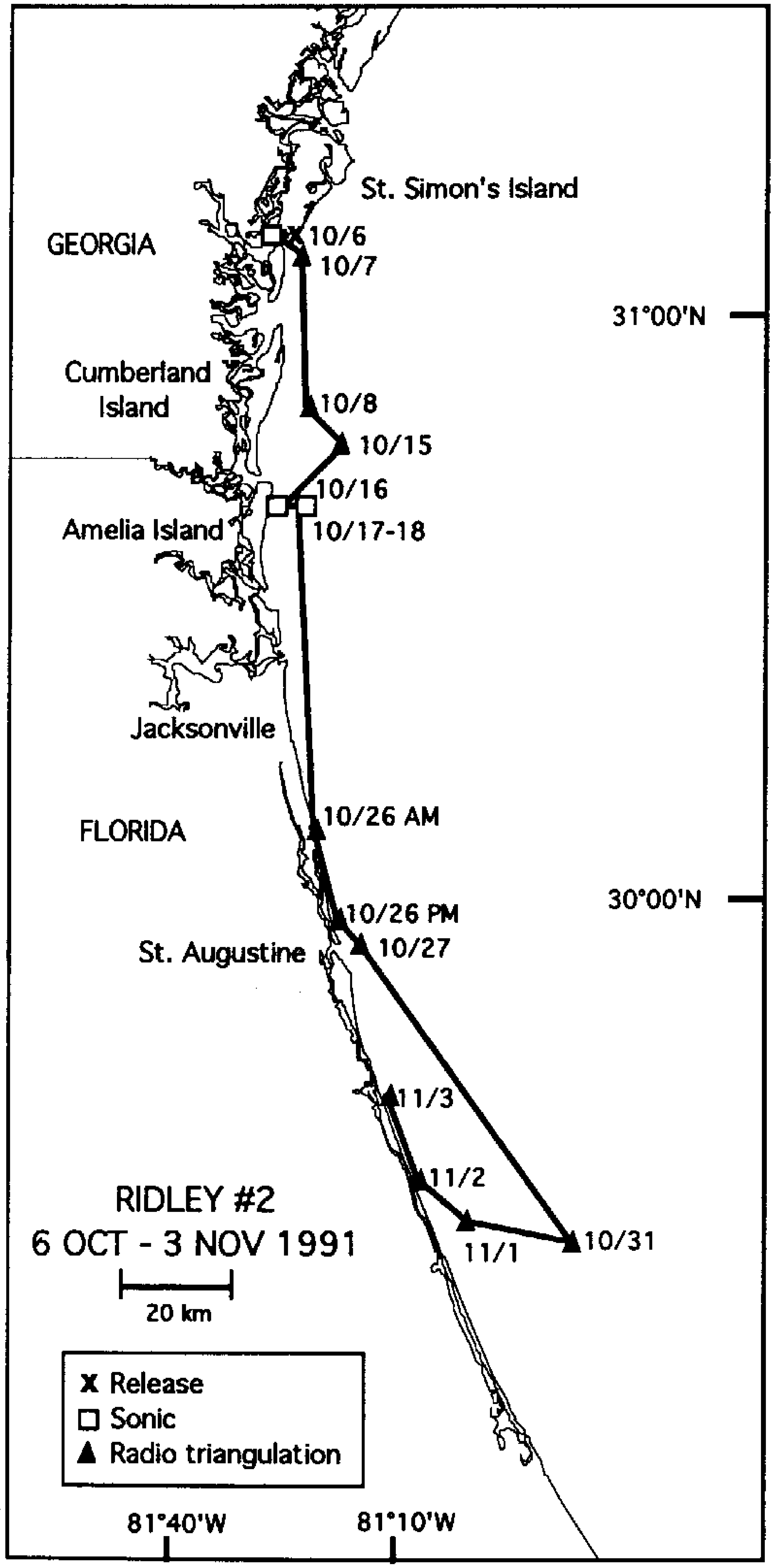

Fig. 2. Locations of Kemp's Ridley No. 2 from 6 October–3 November 1991.

travelled more than 46 km from 25–29 October, and an additional 28 km by 31 October when winds and seas calmed. This contrasts with R1 which showed little southerly movement during the same period. R2 then travelled north approximately 28 km during the next 3 days. After 4 November, 1991 no further radio transmissions were received. During the 29 day tracking period, this sea turtle travelled 202 km south to approximately Daytona Beach, Florida. R2 was always found within 6 km of shore in water depths less than 18 m based on visual sightings and sonic signals. Triangulation of radio bearings placed R2 as far as 29 km offshore where water depth was estimated at less than 24 m. Neither R1 nor R2 appeared to establish temporary residence in coastal channels.

3.1.3. Kemp's ridley No. 3

This nesting sized female, R3, measuring 61 cm SCL was equipped with a satellite transmitter and showed much more rapid southerly movement than the two juvenile Kemp's ridleys discussed above. By the end of the first month after release, R3 had travelled 267 km to Cape Canaveral, Florida (Fig. 3). From mid-November through mid-March, the sea turtle overwintered in the Atlantic Ocean generally within about 40 km of the coast from Cape Canaveral to just north of Stuart, Florida. The maximum recorded distance from shore was 80 km off Cape Canaveral. Northward migration began in mid-March. Between March 18 and April 30, 1992, R3 travelled from south of Cape Canaveral northward to Savannah, Georgia, a distance of approximately 500 km. Northward migration terminated in early May when the turtle reached Port Royal, South Carolina where it remained until July 1, the last day that a location was obtained for this turtle. During this period R3 utilized both inshore and offshore habitat spending a considerable time in many of the tributaries of Port Royal Sound and also travelling offshore as far as 44 km. Rate of movement during the entire period at large ranged from 0.02–31.30 km/h with a mean of 1.42±0.63 km/h. Deletion of the maximum value, which was an outlier, yielded a range of 0.02–8.45 km/h with a mean of 0.82±0.22 km/h. Postwinter migration to the north (Cape Canaveral, FL to Savannah, GA) was more rapid than pre-winter southerly migration (St. Mary's Channel, GA to Cape Canaveral, FL) measuring 12.6 and 8.7 km/day, respectively.

3.1.4. Water temperature

Movement of R3 was analyzed in relation to water temperature using AVHRR sea surface temperature data and tag temperature. There was good comparability between the two data sets. Differences were generally small and could be attributed to inherent variations in accuracy between the two methods. Tag temperature may not always reflect surface water temperature. If a turtle basked on the surface, tag temperature may be higher than ambient water temperature. Similarly, if the satellite received a data transmission shortly after a turtle surfaced from a dive where underlying water temperature was lower than surface water temperature, the tag temperature may be lower than the actual surface temperature.

As R3 moved south along the Florida coast on 13 and 23 October, AVHRR data indicated sea surface temperature was 21–23 °C. Tag temperature was not available for 13 October but measured 24 °C on 23 October. On 14 November AVHRR sea surface

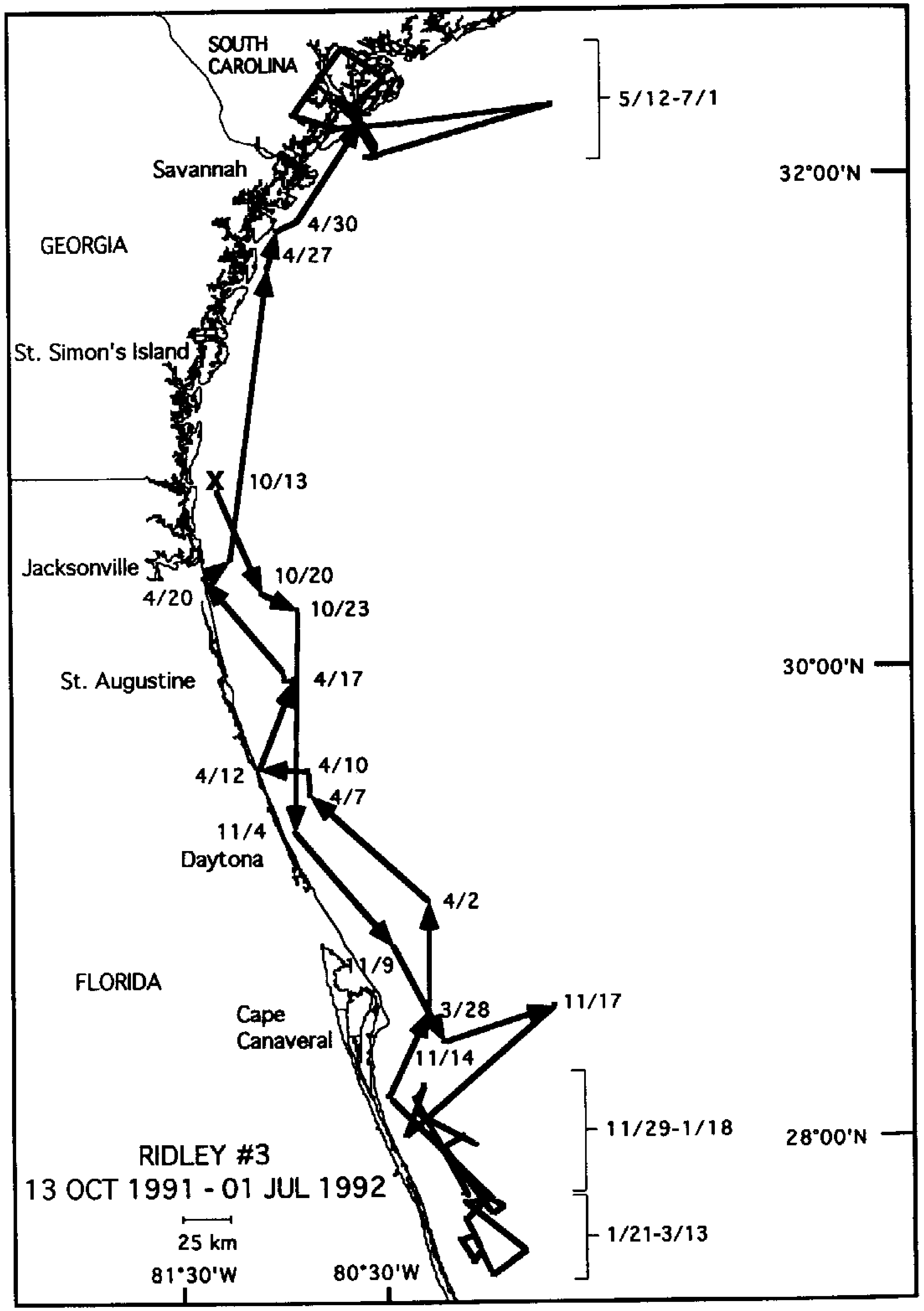

Fig. 3. Movements of satellite tracked Kemp's Ridley No. 3 from 13 October 1991–1 July 1992. Note overwintering south of Cape Canaveral from December through March. Northerly migration began in March and ended in mid-May in South Carolina waters where the turtle remained until July when data transmissions ceased.

temperature at R3's approximate location ranged from 18–25 °C while tag temperature was 22 °C. By 17 November the sea turtle had moved 80 km offshore where AVHRR temperatures in and around a large area of the Gulf Stream exceeded 25 °C and tag temperature measured 24 °C. Approximate water depth for this location as determined from NOAA Chart 411 was 300–750 m. This was the deepest water where a position was recorded. By 17 December R3 had travelled to within 20 km of shore where sea surface temperature was 21–22 °C and tag temperature was 23 °C. Between 17 December and 28 March tag temperature ranged from 19–24 °C. Tag temperatures were 19–22 °C during April when R3 migrated north from Cape Canaveral through Florida. By the end of April R3 was in north Georgia waters and tag temperature measured 18 °C. Positions during May–July placed R3 in South Carolina waters where tag temperature ranged from 19–29 °C with one exception. On June 11 two temperatures were recorded, 17 °C and 28 °C, at a location near Port Royal approximately 10 km offshore in 15 m water depth. The low reading may have reflected the temperature of cold bottom water encountered during a dive.

Tag temperatures varied significantly by season ($P = 0.003$) and month ($P = 0.000$, Table 2). Mean tag temperatures for fall, winter, and spring were 23.3±0.3, 21.1±0.2 and 23.3±0.6 °C. Two summer temperatures measuring 26.7 and 27.1 °C were also recorded. Tag temperatures ranged from lows of 17.5 and 16.9 °C in April and June, respectively, to a high of 29.1 °C in June.

3.2. Surface and submergence behavior

3.2.1. Ridleys No. 1 and No. 2

Mean surface times were brief in comparison to submergence times for both radio tagged sea turtles. Duration of surfacings for R1 ranged from 1 s to 11.8 min (mean 1.8 min) while the range for R2 was 1 s to 14.3 min (mean 1.1 min). Dive duration ranged from 2 s to 147.7 min (mean 33.3 min) for R1 and from 2 s to 115.3 min (mean 20.6 min) for R2.

Table 2
Summary of ANOVA's for diving parameters and tag temperature of Ridley No. 3, a nesting sized female equipped with satellite telemetry.

	P	No. of observations
Percent submergence per 12 h period by:		
Season (fall, winter, spring)	0.006*	54
Day vs night	0.001*	54
Average submergence duration per 12 h period by:		
Season (fall, winter, spring)	0.000*	54
Day vs night	0.006*	54
Mean number of submergences per 12 h period by:		
Season (fall, winter, spring)	0.001*	54
Day vs night	0.195	54
Tag temperature by:		
Season (fall, winter, spring)	0.003*	79
Month (October–June)	0.000*	79

Asterisk denotes significant difference.

Mean surface and submergence durations were plotted for each hour of the day (Fig. 4). Mean duration of day and night surface intervals was not significantly different for R1 ($P = 0.779$) or R2 ($P = 0.094$; Table 3). Mean day vs night dive durations were significantly different for R2 ($P = 0.000$, 13.7 vs 77.3 min) but not for R1 ($P = 0.230$, 32.1 vs 37.2 min, Table 3). R2 showed much longer mean dive durations than R1 at night (Fig. 4). Approximately 75% of R2's day dives were short, less than 10 min, while nearly 75% of the night dives were long, between 90–120 min (Fig. 5). In contrast, dives for R1 were more normally distributed with a peak at 30–40 min during both day and night, although the percentage of day dives less than 1 min was similar. One interesting feature was the absence of any short dives less than 10 min for either turtle at night.

Radio tagged Kemp's ridleys were submerged during 95% of the time monitored. Submergence time varied little between day and night, ranging from 94.6% to 95.2% for R1 and 93.0% to 97.8% for R2.

Obtaining a stable depth reading from sonic transmitters was sometimes difficult. As a result, depth readings from depth-sensitive tags were recorded infrequently. Nevertheless, data indicated that after initial descent, Kemp's ridleys generally remained at a constant depth at or near bottom during submergence events.

3.2.2. Ridley No. 3

Data from 54 time periods of 12 h including 1170 dives were used to statistically analyze average submergence duration (ASD), percent submergence, and number of submergences per 12 h period. Average submergence duration varied by day, night, and season. Mean ASD was higher at night than during the day ($P = 0.006$, Table 2, Fig. 6). Seasonal differences were also significant ($P = 0.000$). Mean ASD was very similar during fall and winter, but showed approximately a 65% decrease in spring. Mean daytime ASDs for fall, winter, and spring were 68.3±12.2, 56.0±8.7, and 24.3±5.3 min while nighttime values were 106.6±12.9, 96.0±14.2, and 33.1±6.7 min. No data were received from the satellite transmitter after only 1 week into the summer season. The sole ASD record collected during summer was 17.2 min at night. Mean ASD for all seasons combined was 63.2±6.3 min.

Data for 82 individual dives representing the last dive made prior to a data transmission from the satellite tag were analyzed separately. Sixty-two percent were 60 min or less in duration, 22% were between 60–120 min, 12% were between 120–180 min, and 4% were between 180–217 min. Mean dive duration was 60.2±5.6 min.

Percentage of time spent submerged for each 12 h period ranged from a low of 73.8% to a high of 99.0% with a mean of 94.0±0.6%. Mean percent submergence was significantly higher at night than during the day ($P = 0.001$, Table 2). The multiple comparisons procedure (Conover, 1980) used in conjunction with the Kruskal-Wallis test showed significant differences between fall and spring ($\alpha = 0.001$) and fall and winter ($\alpha = 0.05$) for mean percent submergence. During the day mean percent submergence was 90.6±7.8% for spring and 95.9±1.1% for fall while nighttime values were 94.4±2.6% and 97.1±1.2% (Fig. 6).

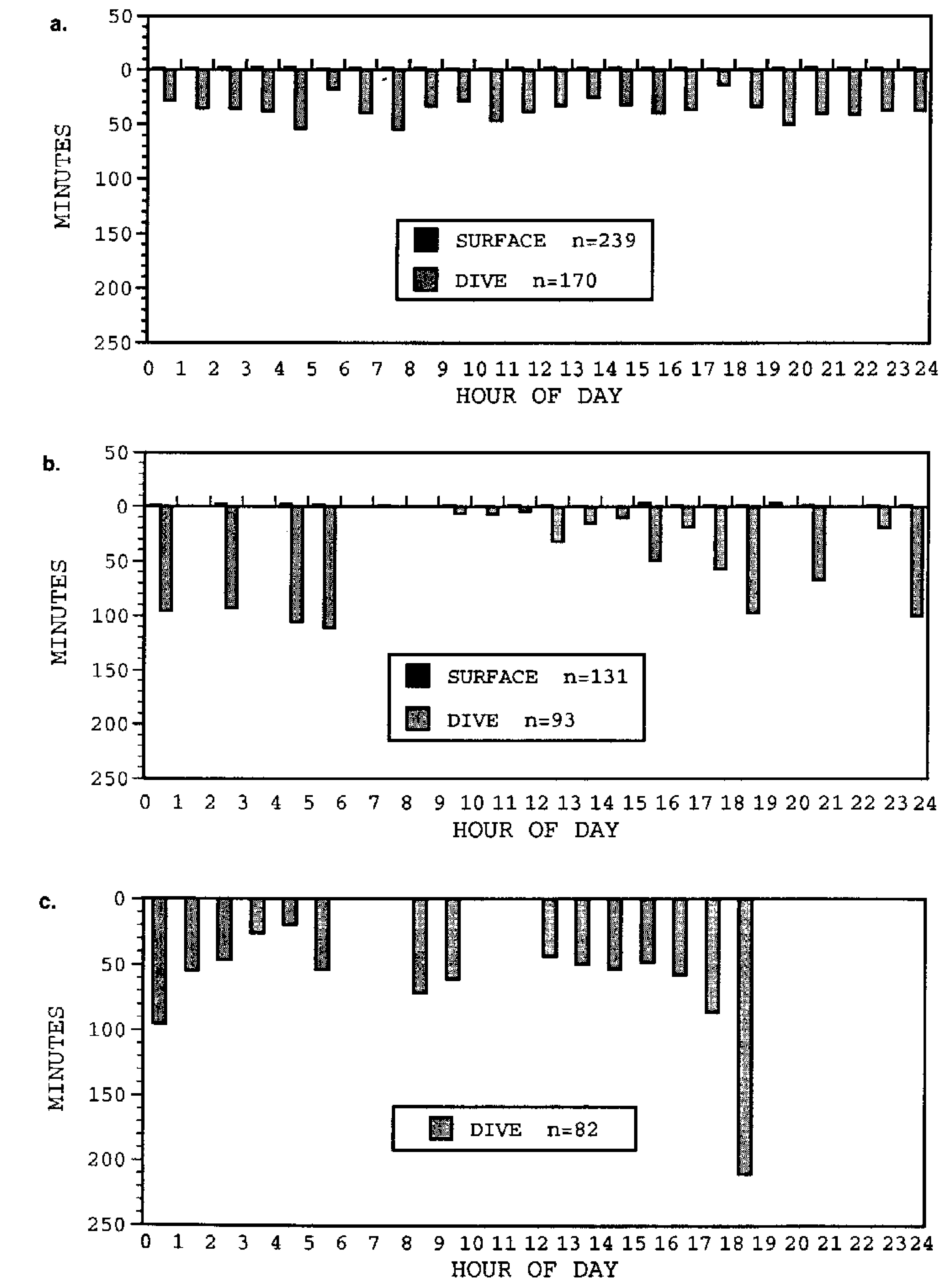

Fig. 4. Mean surface and dive duration by hour of day for Ridleys No. 1, No. 2 and No. 3 (Figs. 4a, b and c respectively). Satellite data for Ridley No. 3 include values for the last dive prior to each data retrieval from the transmitter, but do not include surface durations.

Table 3
t-Test and means for day vs night surface and submergence duration (minutes) for radio tagged juvenile ridleys.

	Day	n	Night	n	P	df
Mean surface interval						
Ridley No. 1	1.8	186	1.9	53	0.779	237
Ridley No. 2	1.0	116	1.8	15	0.094	129
Mean dive duration						
Ridley No. 1	32.1	130	37.2	40	0.230	168
Ridley No. 2	13.7	83	77.3	10	0.000*	91

Asterisk denotes significant difference between day and night durations.

The number of submergences per 12 h period ranged from 4–193. Although the mean number of submergences was higher during the day than at night, the difference was not significant ($P=0.195$, Fig. 6, Table 2). The mean number of submergences was at least three times higher in spring (47.0±15.3 and 27.3±3.5 for day and night) than either fall or winter (12.6±3.7 and 7.5±0.8 for fall, 12.0±1.6 and 8.5±1.0 for winter). This difference was significant ($P=0.001$).

4. Discussion

Literature describing diving behavior and migration of Kemp's ridley sea turtles is limited (Lutcavage and Musick, 1985; Henwood and Ogren, 1987; Byles, 1988, 1989; Schmid and Ogren, 1990, 1991; Standora et al., 1990, 1991; Morreale and Standora, 1991, 1992; Morreale et al., 1992; Epperly et al., 1995a,b; Renaud, 1995; Schmid, 1995). Since sample sizes were often small, results from individual contributions may be strongly influenced by individual variation and are best interpreted in the context of other available data.

4.1. Diving and rate of movement

My results are similar to those of Renaud (1995) who found no significant difference in mean number of submergences during the day and at night for three of four adult and subadult satellite tagged ridleys studied in the Atlantic Ocean and Gulf of Mexico. However, he reported the mean number of submergences per 12 h period was highest in winter not spring, and seasonal means were higher than any found in the present study (56.7–280.9 compared with 7.5–47.0). Byles (1989) placed satellite tags on 18 nesting females at Rancho Nuevo, Mexico and described an overall mean of 69.8 dives per 12 h period. His mean ASD of 18.1 min (s.d. 16.1) for a 12 h period was very different from the 63.2 min value I obtained for a migrating female of nesting size.

Kemp's ridleys spend very little time at the surface. Mean submergence times of 96% (Byles, 1989) and 89% (Renaud, 1995) are comparable to those from this study (94%). Day–night seasonal means described by Renaud (1995) ranged from 77.1–96.7% compared with 87.6–97.1% for the satellite tracked ridley in this study. An even wider

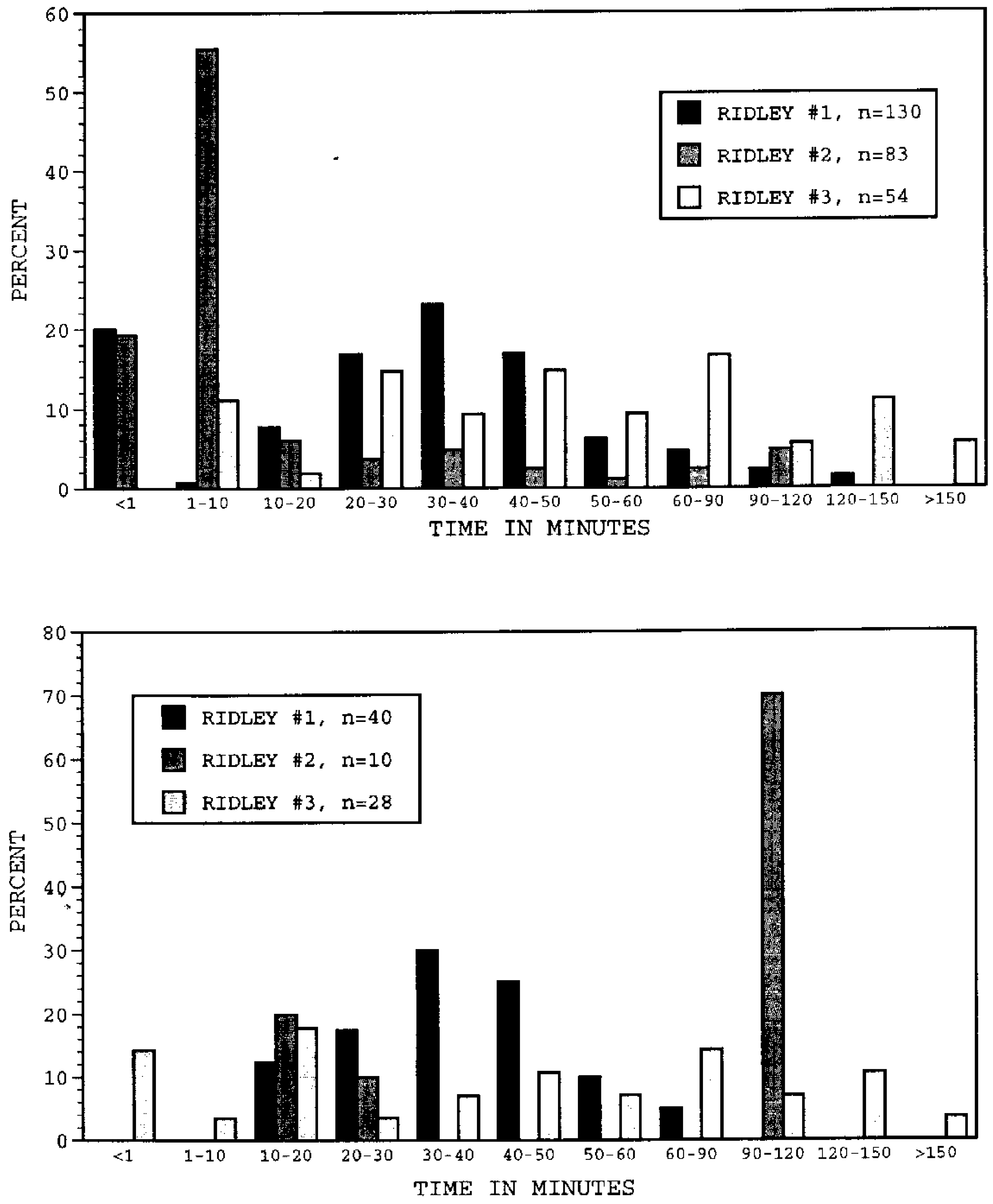

Fig. 5. Percentage of day and night dives by dive duration for Ridleys No. 1, No. 2 and No. 3. Data for Ridley No. 3 only include values for the last dive prior to each data retrieval from the transmitter.

range, 2–92%, was found for ridleys tracked during the day via radio telemetry in Long Island Sound (Morreale and Standora, 1991). Byles (1989) and Renaud (1995) reported no significant difference in percent submergence time between day and night periods although my results and those of Morreale and Standora (1991) indicated more time spent at the surface during the day than at night. Because Kemp's ridley turtles spend so

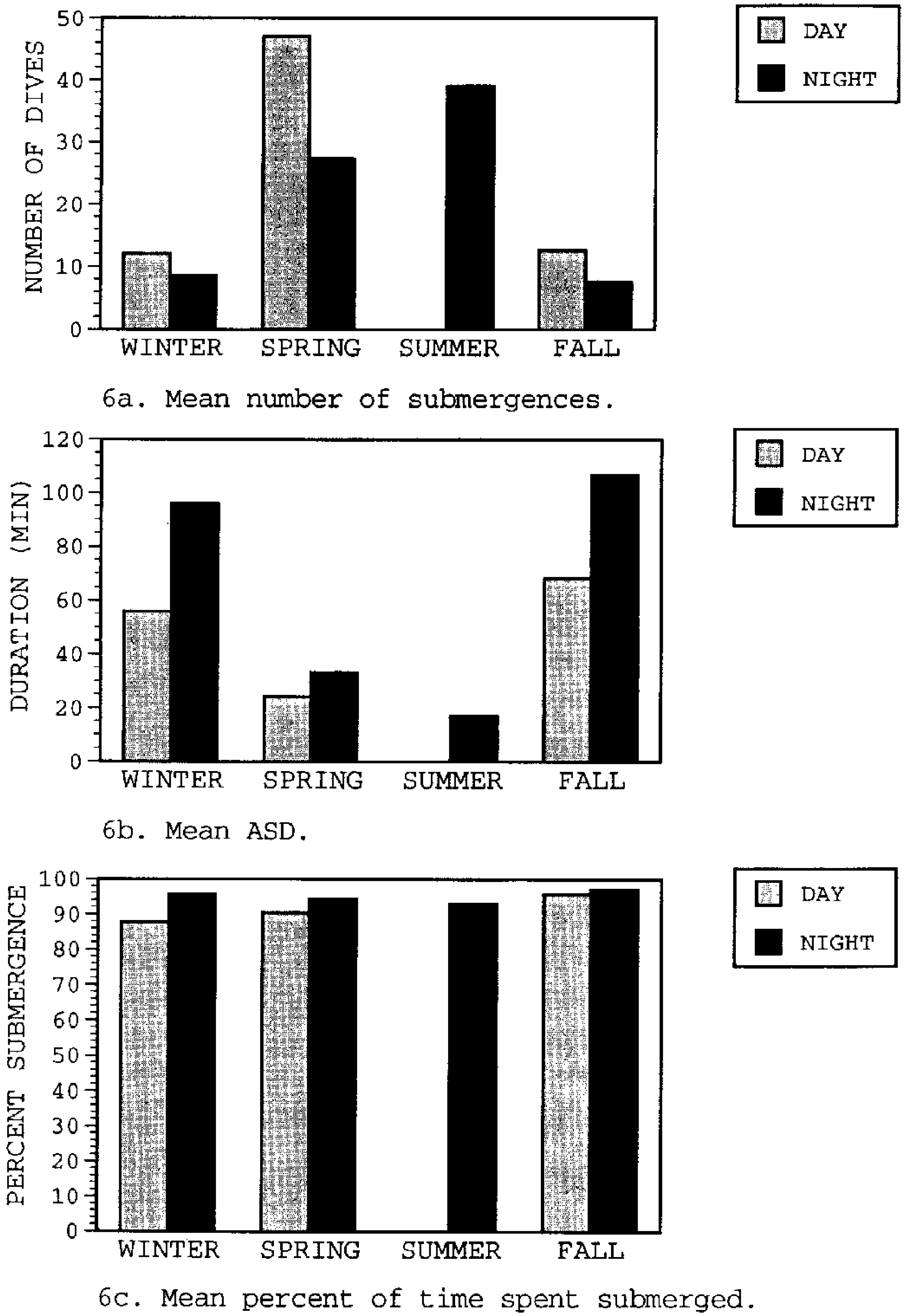

Fig. 6. Mean number of submergences, mean average submergence duration (ASD), and mean percentage of time spent submerged by day (0700–1900), night (1900–0700), and season for Ridley No. 3, a satellite tagged female of nesting size. Each sample represents data collected during a continuous 12 h period. Day and night sample sizes for winter, spring, summer, and fall were 4 and 11, 11 and 12, 0 and 1, and 5 and 11, respectively.

little time on the surface, caution should be used when estimating abundance and population size from surface vessel and aircraft surveys.

Few data are available on the maximum duration of dives. Byles (1989) reported a maximum dive duration of approximately 100 min for satellite tagged ridleys in the Gulf of Mexico. Renaud (1995) cited a 7 h dive for a satellite tagged ridley in the Atlantic Ocean, although he advises that dives longer than 3 h be viewed with caution. While there is evidence for cold temperature dormancy in loggerhead and green sea turtles (Felger et al., 1976; Regal, 1976; Mrosovsky, 1980; Carr et al., 1981), dormancy occurred at temperatures considerably lower than those experienced by the turtles in the present study. Although extreme, the submergence of 217 min found here is conceivable in view of the weeks or months that some turtles can remain submerged during hibernation. However, there is the possibility of error in dive data collected by satellite tags utilizing a salt water switch. The tag recognizes dive termination whenever the circuit between two external poles on the tag is broken, as when the turtle surfaces and the tag is out of water. Although unlikely, it is possible that water-soaked debris entangling the tag could complete the circuit even when the tag is out of the water during a surfacing event. This would prevent the recording of an actual surfacing event and extend apparent dive duration.

Rate of movement can be obtained from satellite data. The average rate (0.8 km/h) for the satellite tagged ridley in this study was similar to those (0.7–1.3 km/h) found by Renaud (1995) for four ridleys tracked in the Atlantic Ocean and Gulf of Mexico. Satellite data have intrinsic errors related to the accuracy of positions. Because movement between successive surfacing locations may not always be linear, rates of movement are not necessarily identical to swimming speed.

4.2. Migration

All three Kemp's ridley sea turtles moved south within 2 days after release. The directional movement demonstrated by these turtles was consistent with seasonal coastal migration. The southward movement of the two juvenile ridleys tagged during October and tracked from Georgia into north Florida waters was similar to that of a flipper tagged juvenile Kemp's ridley released in South Carolina in October 1983 and recaptured in December off north Florida (Henwood and Ogren, 1987). Other researchers have reported southerly movement of loggerhead and ridley sea turtles from northern latitudes to South Carolina, Georgia, and Florida (Morreale and Standora, 1992; Epperly et al., 1995a,b; J. Keinath, pers. comm.). While the present study provides direct evidence of overwintering in south Florida near Cape Canaveral, indirect evidence comes from studies of size distribution. Henwood and Ogren (1987) found the abundance of ridleys appeared highest in Florida during winter, although their data were not adjusted for seasonal variation in fishing effort. Seasonal distribution and winter migration of juvenile ridleys south from New England have also been clearly documented (Standora et al., 1990, 1991; Morreale et al., 1992).

Post-winter northerly migration has also been reported. In February of 1981 and 1984 Henwood and Ogren (1987) tagged two ridleys which migrated northward from Cape Canaveral, Florida to South Carolina and Virginia by the following May and August, respectively. Two ridley turtles tagged in December and February at Cape Canaveral were recovered during July in South Carolina and Georgia (Schmid and Ogren, 1991; Schmid, 1995). I obtained similar results from a satellite tagged female. Coastal waters of South Carolina may represent an important habitat for Kemp's ridleys during late spring and early summer. These data were consistent with the transitory Kemp's ridley population described by Carr (1980) along the Atlantic coast and with the apparent absence of migration around peninsular Florida into the Gulf of Mexico (Schmid and Ogren, 1990, 1991). However, there is one unpublished account of a Kemp's ridley tagged on the Atlantic coast of Florida later nesting in Rancho Nuevo, Mexico (Eric Martin, Ecological Associates, P.O. Box 405, Jensen Beach, FL 34958, pers. comm.). The occurrence of adult Kemp's ridleys on the U.S. Atlantic coast is rare. Two adult ridleys, one with developing ovaries, have been reported from Chesapeake Bay, Virginia (Keinath et al., 1994) while ridleys approaching the minimum size of nesters were documented in North Carolina (Epperly et al., 1995a) and Florida (Schmid, 1995). It is uncertain whether the nesting sized Kemp's ridley monitored in this study was an adult or subadult since neither laparoscopy nor hormone titre were performed. If this turtle was an adult it would lend support to the suggestion by Henwood and Ogren (1987) that mature turtles occasionally forage along the east Florida coast. My data provide clear evidence of overwintering by a Kemp's ridley of nesting size along the central Atlantic coast of Florida, and suggest an overwintering period from mid-November to mid-March, the time when juveniles are present (Schmid and Ogren, 1991).

Although temperature certainly influences sea turtle movements (Carr, 1980; Shoop and Kenney, 1992; Morreale et al., 1992; Morreale and Standora, 1992; Epperly et al., 1995a), a simplistic model in which winter migration is triggered when sea water reaches one specific temperature is not supported by existing data. Water temperature dropped below 15 °C before directed movements suggested the onset of emigration of juvenile ridleys (mean SCL 33 cm) from Long Island Sound (Standora et al., 1990). Kemp's ridley and loggerhead sea turtles were not found in Chesapeake Bay from December through April when water temperature was below 18 °C (Lutcavage and Musick, 1985; Byles, 1988). Water temperature in Brunswick Channel in October was 25 °C when turtles in the present study were released. Since this temperature is clearly too high to induce southerly migration, experimental subjects in this study may have initiated migration at a more northerly latitude.

There are several mechanisms by which temperature may influence a migratory response in sea turtles. A rapid decrease in temperature caused by passage of severe cold weather fronts appears to be a key factor stimulating migration from New England waters in fall (Morreale and Standora, 1992). Since temperature varies with latitude, stimulation of a migratory response may occur when temperature drops through a critical range which is cooler in the north and warmer in the south. Migration is a complex response which may be influenced by multiple factors including air and water temperature, photoperiod, and others.

4.3. Alternative winter habitat

While it is clear that some ridley turtles as well as greens and many loggerheads are found in Florida waters during winter (Henwood, 1987; Henwood and Ogren, 1987; Morreale and Standora, 1992) recent evidence indicates that waters off North Carolina south of Cape Hatteras may represent another source of winter habitat (Epperly et al., 1995a). Turtles travelling south from northern latitudes eventually encounter the barrier islands of North Carolina where the narrow continental shelf may concentrate the animals (Epperly et al., 1995b) near warm water meanders and eddies of the Gulf Stream (Stommel, 1965; Neumann and Pierson, 1966; Lee et al., 1981; Glenn and Ebbesmeyer, 1994a,b; Chester et al., 1994). These eddies commonly occur south of Cape Hatteras (Lee and Brooks, 1979; Pietrafesa and Janowitz, 1979) every winter and represent favorable conditions for sea turtles (Epperly et al., 1995a).

Supporting evidence for this hypothesis comes from the flounder fishery of North Carolina (Epperly et al., 1995a). During January–February catch rates of loggerheads north of Cape Hatteras decreased dramatically, but there was only a moderate decline in the relatively high catch rate south of Cape Hatteras. This indicated use of the south Cape Hatteras area as winter habitat by loggerhead sea turtles.

Information pertaining to overwintering of Kemp's ridleys in this area is limited and conflicting. In a satellite tagging study conducted by Renaud (1995) a Kemp's ridley sea turtle remained in the vicinity of Cape Hatteras from September through January when data transmissions ceased. This apparent lack of migratory behavior suggests the turtle may have remained throughout the winter. However, a dramatic decrease in catch rates of Kemp's ridleys in the flounder fishery during January–February was consistent with emigration of ridley sea turtles from the area (Epperly et al., 1995a). Additional research is needed to clarify seasonal habitat use by turtles on the U.S. Atlantic seaboard.

In conclusion, three Kemp's ridley sea turtles displayed southerly migration from Georgia to Florida during October. A female Kemp's ridley of nesting size was equipped with a satellite transmitter and travelled south much faster than two juveniles tracked with radio/sonic telemetry. The mean submergence time was 94% for radio tracked turtles and 95% for the larger female. Satellite telemetry documented the primary overwintering grounds of the female ridley to lie within approximately 40 km of the Atlantic coast between Cape Canaveral and Stuart, Florida during mid-November to mid-March. Coastal waters of South Carolina were the preferred habitat of this individual during late spring and early summer. Northerly migration in spring was more rapid than southerly migration in fall. AVHRR sea surface temperature data and tag temperature data indicated a thermal preference of approximately 18 °C or greater. Although observed in and around channels, Kemp's ridleys did not appear to establish residency in any dredged shipping channels during winter migration.

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